NEW PERMIAN CRINOIDS FROM AUSTRALIA

by G. D. WEBSTER

ABSTRACT. Thirteen taxa of Permian crinoids are reported from Australia. These crinoids increase our knowledge of the cooler water Australian late Palaeozoic faunas, are dominantly sand substrate dwellers, and provide new fossils which support earlier correlations of recognized Permian strata in eastern and Western Australia. The early Permian age of several Australian species, which are also found in Timor, supports earlier views that the previously assigned late Permian age of the Timor crinoid-bearing Basleo Beds of the Maubisse Formation may be incorrect. Taxonomic reassignment of families previously placed in the Lophocrinacea are: the Pachylocrinidae to the Texacrinacea, based on the similarities of the radial facets and arms branching patterns; the Stellarocrinidae to the Texacrinacea, based on dorsal cup similarities; and the Laudonocrinidae to the Pirasocrinacea, based on dorsal cup and arm morphology. Taxonomic reassignment of four genera previously placed in the Pelecocrinidae, all based on similarity of morphological characters of the dorsal cup of the genus and the family, are: transfer of *Forthocrinus* to the Stellarocrinidae; *Tetrabrachiocrinus* to the Laudonocrinidae; and *Malaiocrinus* and *Depaocrinus* to the Pachylocrinidae. Inadunates recognized for the first time in Western Australia are *Eoindocrinus praecontignatus* and *Tapinocrinus spinosus*. New taxa described are the camerates *Dichocrinus*? *gerringgongensis* sp. nov., *Neocamptocrinus occidentalis* sp. nov., and *Stomiocrinus ferruginus* sp. nov., and the inadunates *Occiducrinus australis* gen. et. sp. nov., *Anechocrinus nalbiaensis* gen. et sp. nov., *Skaiocrinus granulosus* gen. et sp. nov., and *Jimbacrinus minilyaensis* sp. nov.

PERMIAN crinoids were first reported from eastern Australia by M'Coy (1847), Ratte (1885, 1887), Etheridge (1892), and Jack and Etheridge (1892). In 1915, Etheridge described plates of the crinoid *Calceolispongia*, from Western Australia, mistaking them for parts of a sponge. Sieverts-Doreck (1942) reported the stems of two inadunate genera from Tasmania. Teichert (1949) demonstrated the early Permian stratigraphic significance of 14 species of *Calceolispongia* within the Carnarvon Basin of Western Australia and, in 1954, recognized *Jimbacrinus*, another genus of the calceolispongiids, from Western Australia. Three inadunates were reported from Queensland in papers by Dickins (1968) and McKellar (1969).

More recently Willink (1978, 1979*a*, *b*, 1980*a*, *b*) described 35 species, systematically reallocated most of the species previously named from eastern Australia, and demonstrated the stratigraphic utilization of several genera in the Permian of eastern Australia. Webster (1987) described an early Permian crinoid fauna (40 species) from the Callytharra Limestone of Western Australia and considered it closely related to the late Permian fauna reported from Timor by Wanner (1916, 1924, 1937, among others).

At present there are 104 species of Permian crinoids recognized from Australia, 51 from eastern Australia and 53 from Western Australia, with no species common to both regions. These Permian crinoids are very important because they are the only recognized cooler water faunas from the Palaeozoic, they support the concept of seaway connections around northern Australia or across the continental interior during the Permian, and they contain some of the same species as the faunas of Timor.

The purpose of this paper is to describe Artinskian to Tatarian crinoids from Australia, especially from the Quinnanie Shale and Wandagee Formation of the Minilya River drainage, the Wandagee Formation of the Lyndon River drainage, and the Cundlego Formation in the Gascoyne River drainage of Western Australia (text-fig. 1). Unfortunately, precise stratigraphic horizon or detailed locality information is not available for many of the specimens. However, most are embedded in distinctive lithologies and it is possible that precise locality and stratigraphic details can be determined in the future. The material is described at this time because it adds significantly to the

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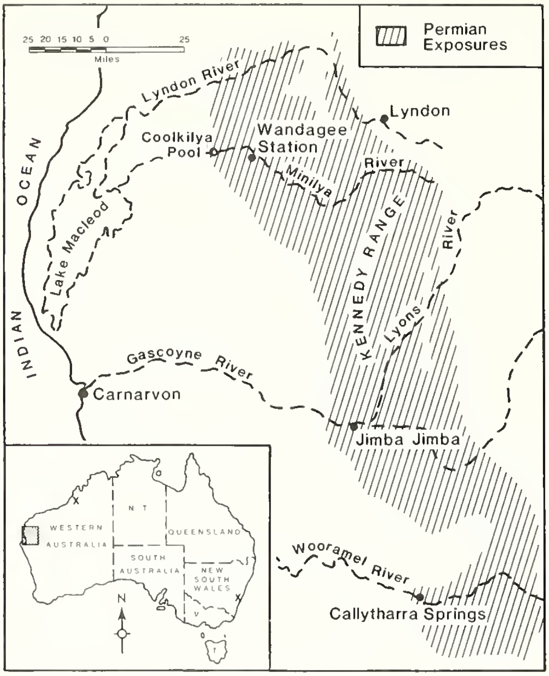


TEXT-FIG. 1. Locality map showing general location of Permian crinoids described from Australia. Enlarged section of Western Australia modified after Teichert 1949. Specific locality information given under each species in systematics section.

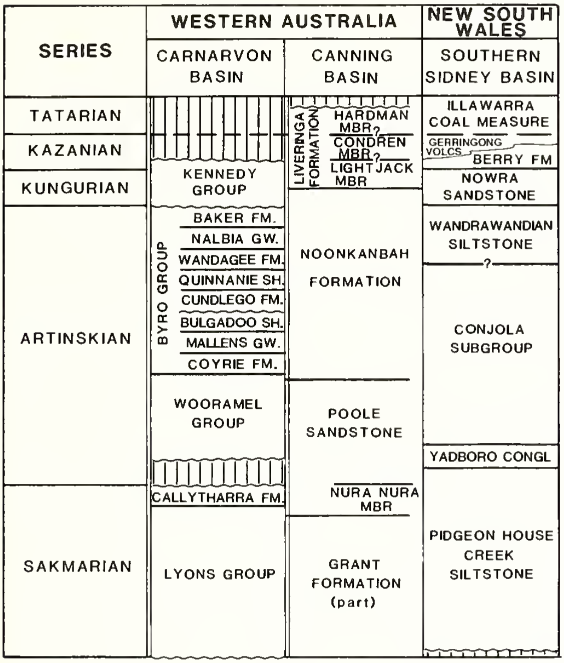
known Permian crinoid faunas and to bring it to the attention of future workers for their applied use. Some taxa add to the increasing number of faunal elements used for correlation between eastern and Western Australia, some raise further questions about the late Permian age of part of the Timor crinoids, and some led to revision of generic and family assignments within the superfamily Lophocrinacea.

SUBSTRATE PREFERENCE

The Permian strata of Western Australia are dominantly clastic sediments; sandstones, graywackes, siltstones, and shales with minor limestones (Trendall *et al.* 1975, among others). Eastern Australian Permian sediments are also dominantly clastic sediments with some volcaniclastics, limestones and coal (Brown *et al.* 1968, among others). The Permian age and series equivalency of the strata in these two areas (text-fig. 2) are based on the occurrence of goniatites and other fossils which have been described in a number of papers since the late 1940s (Teichert 1949; Glenister and Furnish 1961; Thomas Dickins 1954; Dickins 1963; among others).

All specimens reported here, except the mudstone mould of *Dichocrinus*? *gerringgongensis* sp. nov. from eastern Australia and the marl-enclosed unnamed new genus of the Rhenocrinidae from Western Australia, are embedded in fine-grained sandstones or mudstones with interbedded sand stringers, are preserved as hydrous iron oxide replacements of the original calcite, and weather a rust yellow or orange to dark red. Most specimens are interpreted to have lived at, or in close proximity to, the site of burial on a sand or silt substrate. Those specimens with arms or proximal lengths of stem attached were buried rapidly, probably the result of storm kills. The few specimens lacking arms and proximal columnals show no abrasion and may have been transported short distances or undergone a brief time of exposure on the sea floor before burial.

Willink (1979*a*, *b*, 1980*a*) reported species of *Gissocrinus*?, *Nowracrinus*, *Tribrachyocrinus*, *Calceolispongia*, and *Meganotocrinus* from sandstones, some very coarse-grained, of eastern Australia. In the same publications or two others Willink (1978, 1980*b*) reported other species of these same genera and species of *Dichocrinus*? and *Notiocatillocrinus* from mudstones, siltstones



TEXT-FIG. 2. Correlation chart of Permian stratigraphic columns for areas in Australia from which crinoids are reported herein. Columns for Western Australia modified after Trendall *et al.*, 1975; that for New South Wales modified after Willink 1980*b*.

and volcaniclastic rocks of the same region. With the exception of the fauna from the limestones of the Callytharra Formation (Webster 1987), Permian crinoids previously reported from Western Australia were found in terrigenous derived sediments, mostly siltstones and fine-grained sandstones (Etheridge 1915; Teichert 1949, 1954). Fifty-one of the 104 Permian crinoid species from Australia are reported from fine- to coarse-grained clastic rocks.

It is unusual to find crinoids on quartz sand substrates as most Palaeozoic crinoids are found in fine- to coarse-grained limestones, claystones and marls (Lane *in* Moore and Teichert 1978, p. 344). Some inadunates in the late Palaeozoic were moderately common in terrigenous derived muds (Lane *in* Moore and Teichert 1978, p. 344). Ausich *et al.* (1979) reported an early Carboniferous community dominated by poteriocrine inadunates which occurs in interdistributary siltstones and distributary channel fine-grained sandstones in the Borden Delta of Indiana and Kentucky.

The adaptation to life on a sand substrate by some poteriocrinid inadunates and a few camerates occurred in or before the early Carboniferous (Ausich *et al.* 1979). The adaptation of other poteriocrinid, cyathocrinitid, and rhenocrinid inadunates as well as other camerates in the Permian of Australia apparently accompanied an adaptation to the cooler waters of the more southerly position of Australia during the late Palaeozoic.

The crinoids described are dominantly poteriocrine inadunates, seven species, but include four species of camerates and one cyathocrinitid inadunate. Other than being fairly robust forms, no morphologic feature which might be interpreted as an adaptation to a sand substrate was found to be common to all sand substrate dwelling species. The abundance and diversity of the sand substrate faunas of the Permian of Australia are the greatest known in the Palaeozoic. Additional study of these faunas is needed as most of the earlier collections were made for stratigraphic purposes and sedimentological data necessary for palaeocological studies were not recorded.

CORRELATION

Teichert (1951) pointed out the Tethyan affinities of the marine Permian faunas of Western Australia, noting their diversity, abundance and widespread occurrence. Western Australian crinoid faunas described by Teichert (1949) and Webster (1987) also show Tethyan similarity in kind, are most closely related to the Timor faunas, and have noted affinities to eastern Australian faunas.

Although the Western Australian crinoids are most closely related to the Timor faunas, correlation of the two faunas is problematic. Timor crinoids are reported from several localities and horizons within the Maubisse Formation, such as the Basleo Beds, etc. (Wanner 1914–1949). The Maubisse Formation is a sequence of highly fossiliferous limestones containing some reefal buildups and eruptive rocks including many vesicular basalts (Audley-Charles 1965). The Maubisse Formation occurs in allochthonous thrust blocks, that were thrust southward from an unknown northern source area (Audley-Charles 1965). Furthermore, Audley-Charles (1965) considers the Maubisse Formation to represent the northern margin of the Westralian geosyncline during part of Permian time. Contemporaneous southern shelf margin deposits included the Permian strata of the Canning Basin and Carnarvon Basin of Western Australia.

In a series of papers between 1914 and 1949 Wanner described the crinoid faunas of Timor and reported them to be of early and late Permian age, mostly the latter. Webster (1987) questioned the late Permian age of the Timor faunas because: there are several mutual species in the crinoid faunas from the Callytharra Limestone and the Basleo Beds; crinoid genera and species are generally short lived, geographically restricted, and good index fossils; and the goniatite control on the Permian section of Western Australia is well documented whereas the stratigraphy of the Timor crinoid-bearing beds is not defined.

Species of *Stomiocrinus*, a camptocrinitid, and an indocrinid in the Wandagee Formation show close relationship to species of these same taxa in the Timor faunas. *Tapinocrinus spinosus* occurs in both the Wandagee Formation and the Basleo Beds. The eastern Australian Artinskian species *Dichocrinus*? *australis*, *D*? *darlingtonensis*, *Neocatillocrinus oakiensis*, *N. nerimberae*, *Neocamptocrinus bundanoonensis*, *N. wardenensis* and *N. millerensis* show relationship to the Timor 'late Permian' faunas. These mutual occurrences provide additional support for a coeval age and paleogeographic proximity for the crinoid-bearing beds of Timor, eastern Australia, and Western Australia. Until the internal stratigraphic and structural relationships of the allochthonous blocks of Timor are completely understood, the late Permian age of the Timor crinoid bearing beds should be questioned.

The relationship of the Permian marine faunas of Western Australia and eastern Australia has been discussed in several papers in the past 25 years (Teichert 1951; Wass 1969, 1970; Stehli 1971; McClung 1975; Runnegar and Campbell 1975; among others). Permian crinoid genera common to eastern Australia and Western Australia are *Neocamptocrinus*, *Notiocatillocrinus*, and *Calceolispongia*. Although no crinoid species occurs in both areas, species such as *Neo. millerensis* and *Neo. occidentalis*, *Neo. bundanoonensis* and *Neo.* sp. nov., *No. nerimberae* and *No. callytharraensis*, and *C. lizziensis* and *C. spinosa* are closely related. Crinoids strongly support earlier views that migration pathways around the northern margin or across the central interior of the Australian continent were actively open during part of the Permian.

SYSTEMATIC PALAEONTOLOGY

Crinoid terminology follows the Treatise on invertebrate paleontology, pt. T, Echinodermata (Moore and Teichert 1978). All measurements are linear and in mm. Specimens are reposited in the University of Western Australia (UWA) and the Australian Bureau of Mineral Resources (CPC).

Subclass CAMERATA Wachsmuth and Springer, 1885
Order MONOBATHRA Moore and Laudon, 1943
Family DICHOCRINIDAE Miller, 1889

Diagnosis. Crown elongate, usually small. Calyx bowl- to globose- to truncated cone-shaped. Basals two, equal, with A-CD interbasal suture. Radials five, separated on posterior side by primanal in line of radial circlet. Tegmen low to inflated, with hypertrophied wing plates, or secondarily simplified to five orals, in advanced genera. Free arms primitively uniserial, two to four in each ray, becoming biserial, four to six in each ray in advanced forms. Stem round transversely and straight, or coiled and bilaterally symmetrical.

Remarks. Broadhead (1981) recognized three subfamilies of the Dichocrinidae: (1) the Dichocrininae Miller, 1889, have the second primibrachial axillary, and the transversely round stem is uncoiled; (2) the Camptocrininae Broadhead, 1981, are similar except the stem is coiled, bilaterally symmetrical and cirrae-bearing; and (3) the Talarocrininae Ubaghs, 1953, are characterized by an inflated tegmen, axillary first primibrachials, and a transversely round stem. The Dichocrininae and Talarocrininae are most diverse in the early Carboniferous, whereas the Camptocrininae are most diverse in the Permian. Permian camptocrinids have been reported from Timor (Wanner 1916, 1924, 1937), Australia (Willink, 1980*a*, *b*; Webster 1987) and Russia (Yakovlev 1927). Their abundance and diversity in Permian strata of Australia offer potential for correlation.

Subfamily DICHOCRININAE Miller, 1889
Genus DICHOCRINUS Münster, 1839

Dichocrinus? *gerringgongensis* sp. nov.

Plate 3, fig. 1

Diagnosis. Monocyclic, bipartite base, basal flange on cup, and non-aligned nodes on basal and radial plates, second primibrachial axillary, isotomous branching, 10 uniserial arms, stem uncoiled.

Type and locality. An external mould (UWA 62961) found by Dr J. E. Glover in a gray mudstone in Permian strata, on the coastal platform 0·8 km south of Gerringgong, New South Wales. The precise locality and horizon were not recorded.

Etymology. The trivial name is taken from the town of Gerringgong, near where the specimen was found.

Description. Crown moderately large (estimated 5 cm length), elongate. Cup bowl-shaped, higher than wide (estimated 2 cm to radial summit, 1·6 cm wide), widest a little below radial facets; prominent basal flange; basals two, form base of bowl, slightly impressed proximally, upward and slightly outflaring distally, subhorizontally projecting flange slightly below midheight, interbasal suture from middle of primanal to middle of A radial; radials five, higher than wide, gently convex transversely and longitudinally, in contact laterally except on primanal, facet below distal tip; primanal elongate longitudinally, gently convex transversely and longitudinally; coarse node and short oblique ridge ornamentation on basals, radials and primanal; tegmen not exposed. Arms ten; brachials strongly convex transversely, gently to moderately convex longitudinally, wider than high, uniserial, cuneate, isotomous division on IBr_2, no further subdivisions; pinnules slender, one per brachial alternating on sides of arm. Stem round (approximately 12 cm preserved), heteromorphic, alternating nodal and internodal proximally, distally homeomorphic; strongly rounded epifacet, articulum unknown, cirri unknown.

Remarks. D? *gerringgongensis* is the third species questionably assigned to the genus from Permian strata of eastern Australia. Willink (1980) described *D*? *australis* (late Artinskian from New South Wales) and *D*? *darlingtonensis* (early Artinskian from Maria Island, Tasmania). These three species form an evolutionary lineage and are closely related in cup shape and coarse noded ornamentation. *D*? *gerringgongensis* is distinguished by the presence of a prominent basal flange with non-aligned nodes. It is intermediate between *D*? *darlingtonensis*, which lacks the prominent basal flange and the nodes are non-aligned, and *D*? *australis*, which has aligned nodes on the basals and radials with a weak basal flange. Although the exact horizon is not known for *D*? *gerringgongensis*, the morphological affinities to *D*? *darlingtonensis* and *D*? *australis* suggest an Artinskian age, with *D*?

gerringgongensis evolving from *D*? *darlingtonensis* by development of the basal flange. *D*? *australis* evolved from *D*? *gerringgongensis* with the alignment of the nodes on the basals and radials.

D? *darlingtonensis* is from a limestone, whereas *D*? *australis* is from the Wandrawandian Siltstone (Willink 1980) and *D*? *gerringgongensis* is from a mudstone. Each is thought to have lived in or very near the site of burial, because they have associated brachials and columnals. Thus these Permian forms apparently had a wide tolerance for substrate type or the three species represent adaptive radiation into different environments.

Broadhead (1981) reviewed the subfamily Dichocrininae and considered the morphology of the tegmen to be an important generic character. Unfortunately, the tegmen is unknown for all three Australian species resulting in the questionable assignment to the genus.

Of the 29 species of *Dichocrinus* that Broadhead (1981) recognized, only two, from the Westphalian of Texas, are known from post early Carboniferous strata and all are known from Europe, North America or Russia. The three Permian species from Australia represent radiation into cooler water environments from a common ancestor.

Subfamily CAMPTOCRININAE Broadhead, 1981

Genus NEOCAMPTOCRINUS Willink, 1980*a*

Diagnosis. Calyx generally large, subquadrangular in lateral view. Basals bipartite, weakly upflared; radials and equal-sized primanal in second circlet, strongly upflared. Radial articular facets trifascial. Tegmen inflated, composed of orals, interambulacrals and anals symmetrically arranged about A-CD plane of symmetry. Orals five, CD enlarged, dome-like, deltoid or semi-cylindrical, madreporitic. Interambulacrals variable in number, commonly two or more in each interray. Anals numerous, serially arranged to form protuberance at posterior. Arms uniserial, isotomously branched, usually on IBr_2 and $IIBr_2$. Stem coiled, bilateral for entire length. Nodal pairs bear solitary or bundled marginal cirri. Rudimentary cirri present or absent. (After Willink, 1980*a*.)

Neocamptocrinus occidentalis sp. nov.

Plate 1, figs. 1–6, 12–14

Diagnosis. A *Neocamptocrinus* with an inverted V-shaped ridge on the posterior oral immediately above the anal opening; coarse central nodes on all orals; no ornament or with fine granular ornament on the basals, radials and primanal; and four to seven arms per ray.

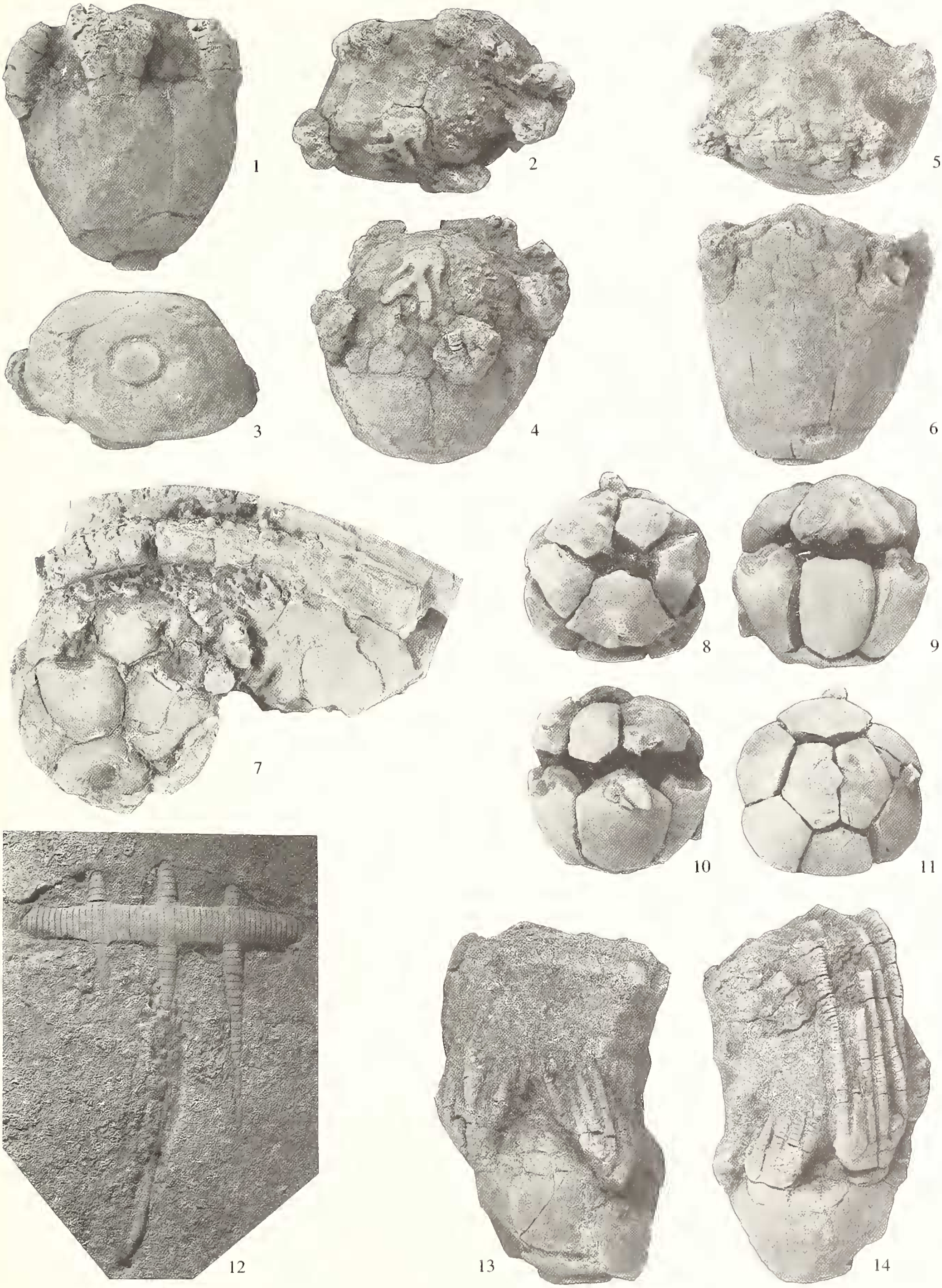
Types and locality. The paratypes, four partial crowns (CPC 27449–27452) and a pluricolumnal (CPC 27453) are from a single slab containing associated crowns of *Jimbacrinus bostocki*. The holotype (CPC 27448) is a partial crown on a small slab. Both slabs are from an unspecified horizon in the Cundlego Formation, late Artinskian, along the Gascoyne River two miles upstream from the Jimba Jimba Homestead. This is the type locality for *J. bostocki* and the slabs are part of the original material studied by Teichert (1954) when he described *Jimbacrinus*.

Etymology. The trivial name *occidentalis* is Latin for western and refers to the Western Australian occurrence of the species.

EXPLANATION OF PLATE 1

Figs. 1–6, 12–14. *Neocamptocrinus occidentalis* sp. nov. 1–4, A ray, oral, basal, and CD interray views, respectively, of paratype CPC 27450; ×2. 5, 6, oral and CD interray views, respectively, of paratype CPC 27449; ×2. 12, exterior view of paratype CPC 27453; ×1. 13, 14, CD interray and A ray views, respectively, of Holotype CPC 27448; ×1·5.

Figs. 7–11. *Neocamptocrinus* sp. nov. 7, D and E ray view, CPC 27455; ×1·5. 8–11, oral, CD interray, A ray, and basal views, respectively, of CPC 27454; ×1·5.



WEBSTER, *Neocamptocrinus*

Description. Crown of moderate size, elongate, widest where arms branch on secundibrachials. Calyx elongate bowl-shaped, higher than wide; fine granular ornament on basal circlet, radials and primanal, or lacking ornament. Basal circlet large, gently upflared, visible in lateral view, bipartite, suture in A ray-posterior plane of bilateral symmetry. Radials five, higher than wide, widest below base of arm facets, steeply upflared to subvertical, gently convex transversely and longitudinally, strongly incurved distally, basal sutures concave adorally. Arm facets angustary, two-fifths width of radial slightly below distal shoulder of radials, gently slope outward; transverse ridge extends full width of facet; outer facet area crescent-shaped with low marginal ridge and low ligament ridge separated by shallow ligament furrow; inner facet area not exposed. Primanal in radial circlet, same size and shape as radials, distally adjoined by three plates in tegmen.

Tegmen gently arched, formed of multiple interambulacrals, five large orals, and multiple anals in posterior interray. Interambulacrals a series of 8–12 plates, with variable number of small plates in two or three rows above a basal row of three plates. Orals form central circlet at top of tegmen; posterior oral largest, adjoined by other four, with a prominent inverted V-shaped ridge along the proximal edge immediately above the anal opening, may have a centrally adjoined parallel ridge distally. A and E orals smallest, B and D orals of intermediate size, all bearing coarse central node. Anal series 3:5:6+ ; anal opening central, slightly protruded in third row, surrounded by numerous small plates.

Arms slender, retaining same width until distal tips, 4–7 per ray, first and second branches isotomous, endotomous thereafter; all branching on second brachial of series. Brachials strongly convex transversely, uniserial proximally, cuneate medially, biserial distally. Second primibrachs much wider than long, laterally fixed to interambulacral plates. Secundibrachs wider than long, more strongly convex transversely than primibrachs, first secundibrach may be fixed to interambulacrals. Tertibrachs through pentibrachs more strongly convex transversely than primibrachs or secundibrachs. Pinnules slender, one per brachial.

Stem facet impressed in basal circlet, elliptical with long axis at an angle of less than 90° to the plane of bilateral symmetry. Proximal columnals homeomorphic, gently convex latera, symplectial articulation; articulum flat, areola wide, crenularium narrow, twice width of latus; lumen small, round. Measurements are given in Table 1.

TABLE 1. Measurements of *Neocamptocrinus occidentalis*

	Holotype CPC 27448	Paratype CPC 27449	Paratype CPC 27450
Crown			
Height (incomplete)	—	39·9	—
Width	—	21·1	—
Calyx			
Height	25·4	—	20·5
Width (average)	19·6	18·3	13·8
Diameter BB circlet	14·0	—	10·8
Height R (A ray)	14·6	13·2	11·9
Width R (A ray)	10·8	10·8	8·6
Height IBr_1	1·2	1·5	1·2
Width IBr_1	4·7	5·1	3·7
Height IBr_2	1·2	1·0	0·9
Width IBr_2	5·0	5·8	4·2
Length proximal columnal	4·6	5·3	4·0
Width proximal columnal	3·5	3·8	3·0

Note: All specimens slightly crushed or distorted.

Remarks. *Neocamptocrinus* was described from eastern Australia (Willink 1980*a*) and is distinguished from other Camptocrininae by the presence of numerous interambulacral plates and five large orals in the tegmen. Three of the species described by Willink (1980*a*) are based on calyces. Two, *N. bundanoonensis* and *N. wardenensis* have calyx plates bearing different types of coarse ornament, neither of which are developed on *N. occidentalis*. The third species, *N. millerensis*, although probably based on a juvenile, has more elongate radials, a higher basal circlet and lacks the ornament on the orals that is present on *N. occidentalis*.

The fine granular ornament on the basals, radials and primanal of paratypes CPC 27451 and 27452 is poorly preserved. It is uncertain if fine granules were present on all the specimens, but not preserved in the hydrous-iron oxide replacement of the calcite, or if this is an intraspecific or specific character.

The excellent preservation of the tegmen on three of the specimens shows the spatial relationships of the interambulacrals and oral plates. Ambulacral trackways into the calyx were directed under the proximal end of each of the orals, which were elevated above the radials by the interambulacrals. The coarse inverted V-shaped ridge on the posterior oral is interpreted as a diverting structure, directing faeces away from the oral surface of the tegmen.

Associated pluricolumnals within the same slab as the calyces are subrectangular in lateral section, heteromorphic with 9–11 internodals per noditaxis. Cirri are circular in transverse section laterally extended for several centimetres, and initiate at paired nodals, overlapping slightly onto the adjacent two internodals. None of the pluricolumnals is attached to the proximal columnals and intermediate columnals were not found in the disarticulated material in the matrix.

Broadhead (1981) suggested that the small cup size and enrolled stem with protecting cirri indicated that the Camptocrininae were moderately rheophilic to moderately rheophobic feeders. The dense feeding net that would have been present on *N. occidentalis* when in the feeding posture, larger cup size, and occurrence in a fine-grained sandstone suggest that it was a rheophilic feeder in a moderate current condition. Neocamptocrinids from eastern Australia (Willink 1980*a*) were reported from mudstones (*N. bundanoonensis*), siltstones (*N. wardenensis*, *N. gremialis*), and sandstones (*N. millerensis*). All were probably living in moderate energy environments and rheophilic feeders. The burial of multiple specimens of both *N. occidentalis* and *Jimbacrinus bostocki* in a single slab with only moderate disarticulation of the column and loss of distal parts of the arms for both species suggests a mass kill during a storm with rapid burial. There is no suggestion of extensive transport before burial.

Neocamptocrinus sp. nov.

Plate 1, figs. 7–11

Material and locality. Four specimens (CPC 27454–27457) from the late Permian, Tatarian, Hardman Member of the Liveringa Formation, from an undesignated locality in the Millyit Range, Fitzroy Trough of the Canning Basin, Western Australia; Wapet Collection, Bureau of Mineral Resources. The specimens are placed in open nomenclature because the precise stratigraphic and geographic localities are not known. There is strong probability that future collecting in the Canning Basin will establish the stratigraphic position and possibly the original locality for the species.

Description. Calyx globose, bowl-shaped, slightly higher than wide. Bipartite basal circlet low, distal tips gently upflared, visible in lateral view. Radials and primanal slightly longer than wide, moderately convex longitudinally, slightly convex transversely. Tegmen strongly arched, composed of five prominent orals, four interambulacrals and four anal plates in a series of 3:1. Posterior oral largest, with gently rounded ridge adjacent to anal opening; adjoined laterally by other four orals. Proximal columnal large, elliptical in cross-section. No ornamentation on basals or radials. Some orals have a gently rounded central node.

Remarks. Three of the four crushed and partly disarticulated specimens of *Neocamptocrinus* sp. nov. have closely associated parts of the coiled column, which relates them to the camptocrinines, not the dichocrinines. The enrolled column with numerous cirri are slightly separated from the calyces, but are considered to have been attached prior to compaction of the enclosing sediment and concurrent distortion, crushing, and disarticulation. The specimens are enclosed in a claystone with thin interbeds of fine-grained sandstone.

One specimen (CPC 27454) was reconstructed after removing the plates from the matrix (Pl. 1, figs. 8–11). The slight difference in size of each of the radials and primanal and unique length and angles of plate sutures between the radials and basal circlet simplified the reconstruction of the cup and oral circlet. Absence of the anals, most intrambulacral plates, and small parts of two of the orals precluded a precise reconstruction and positioning of the tegmen. The globose shape of the theca and inflated tegmen approximate the original form sufficiently to permit shape interpretations and comparisons with other known forms.

These specimens are referred to *Neocamptocrinus* because they have one interambulacral plate per interray between the radials and the orals, and multiple plates in the anal series above the primanal. Among the Camptocrininae only *Neocamptocrinus* has interambulacrals and multiple anals in the tegmen (Broadhead 1981).

Neocamptocrinus sp. nov. is very similar in shape, but lacks the ornament and more numerous interambulacrals and anals present on *N. bundanoonensis*. The latter species is a Kazanian form from New South Wales (Willink 1980*a*). The morphological similarities and late Permian age of *N.* sp. nov. and *N. bundanoonensis* suggest seaways were open between eastern and Western Australia in the late Permian and that both forms were derived from a common ancester.

Genus STOMIOCRINUS Wanner, 1937

Diagnosis. Crown small to medium in size, elongate, slender. Calyx elongate, globose to truncated cone-shaped. Basals bipartite, subequal. Radials large form two-third of dorsal cup. Solitary anal plate in radial circlet, narrower than radials. Radial facets oval in outline, angustary, elevated producing radial notches, slope outward. Orals large, slightly inflated, do not meet at centre of tegmen; CD oral largest, projects slightly beyond centre of tegmen. Ambulacral grooves along mutual shoulders of adjacent orals. Arms ten, uniserial. Brachials cuneate, inflated, IBr_2 axillary, bear one pinnule each on alternate sides of arm. Stem bilaterally symmetrical bearing cirri, coiled.

Stomiocrinus ferruginus sp. nov.

Plate 3, figs. 4 and 5

Diagnosis. A *Stomiocrinus* with truncated base, high conical cup, ten uniserial arms with cuneate brachials and one pinnule per brachial on alternating sides of arms.

Type and locality. The holotype (UWA 27006), is imbedded in fine-grained sandstone associated with gastropod and bivalve fragments from the upper part of the Wandagee Formation along the Lyndon River, Western Australia. Precise horizon and locality not recorded.

Etymology. The trival name refers to the preservation of the specimen. All plates are replaced with hydrous iron oxides.

Description. Crown slender elongate, widest at three-quarters height; cup nearly cylindrical high truncated cone expanding gently above basals, unornamented, sutures gently impressed, crushed parallel to A-CD symmetry plane; basal circlet half again as wide as high, walls subvertical, formed by two equal plates, one each on either side of symmetry plane; five RR over half as long again as wide, gently convex longitudinally, moderately convex transversely, angustary radial facets project above the distal surface, facet details not observable; anal plate similar to but narrower and slightly shorter than RR; Brr cuneate uniserial, wider than high becoming more pronounced distally, strongly convex transversely, proximal IIBrr gently convex longitudinally, distal IIBrr strongly convex longitudinally with lateral blunt spinose projection in zig-zag manner along arm; Brr facets much deeper than wide, ambulacral groove small, narrow V-shaped; arms ten, IBr_2 axillary in all rays, one pinnule per brachial, projecting on alternate sides of the arm. Stem facet round, large, no details preserved; oral plates not observable.

Measurements: Crown height 33·2, width 12·6; cup height, 8·4, maximum width 6·7, minimum width 5·5, average width 6·1; basal circlet diameter 3·9, height 2·8; R height, 6·2, width 3·7; anal height 5·7, width 1·9; IBr_1 height 1·2, width 2·1; $AxIBr_2$ height 2·0, width 2·5; $IIBr_1$ height 1·4, width 1·8; diameter stem facet 2·4.

Remarks. Stomiocrinus is known from Artinskian deposits of Russia (Yakovlev *in* Yakovlev and Ivanov 1956) and the Basleo Beds of Timor (Wanner 1937). *S. ferruginus* shows affinity with both the Russian and the Timor species, but is most similar to *S. minimus* Wanner, 1937 from Timor. The more nearly vertical walled basal circlet and relatively narrower anal plate distinguish *S. ferruginus*. All other species of the genus, based on the thecae and reported from carbonate substrates, have basal circlets that flare moderately to strongly up and out. The excellent state of preservation in a fine-grained sandstone and abundant associated invertebrate fauna suggests little if any transport of the fauna after death.

This is the first knowledge of the arms of *Stomiocrinus*. The occurrence of two primibrachs and isotomous branching on the second primibrach are features typical of most dichocrinids. A rheophilic feeding pattern is suggested by the lengthy arms and slender pinnule development.

The classification of *Stomiocrinus* is somewhat uncertain. Yakovlev (*in* Yakovlev and Ivanov 1956) reported disassociated thecae and bilaterally symmetrical columns that he referred to *Stomiocrinus*. Broadhead (1981) accepted Yakovlev's interpretation of *Stomiocrinus* and assigned it to the subfamily Camptocrininae, which have bilaterally symmetrical columnals that enroll. Until articulated theca and columnals of *Stomiocrinus* are found some uncertainty remains about the subfamily affinity.

Order CLADIDA Moore and Landon, 1943
Suborder CYATHOCRININA Bather, 1899
Superfamily CYATHOCRINITACEA Bassler, 1938
Family CYATHOCRINITIDAE Bassler, 1938

Comments. Four cyathocrinitid genera are recognized by Moore *et al.* (*in* Moore and Teichert 1978). They share the common features of a laterally positioned, short, stout anal sac with a vent at or near the apex, a single large primanal in the cup and angustary arm facets. Two of the four genera are known from very few specimens and restricted in geological and geographical distribution. *Anarchocrinus* is monotypic, of middle Ordovician age, and known from Estonia. The two species of *Ceratocrinus* are of late Permian age from Timor. A third genus *Gissocrinus* has 27 reported species (Bassler and Moody 1943; Webster 1973), is of late Silurian to early Devonian age and found in North America, Europe and Russia. *Cyathocrinites*, the fourth genus, has 96 species assigned to it (Bassler and Moody 1943; Webster 1973, 1986), a range of Silurian to Permian, a cosmopolitan distribution, and is in dire need of a systematic review.

Since a thorough review of *Cyathocrinites* is beyond the scope of this investigation, a few comments on the morphology of the cup as shown on the 96 species currently assigned to the genus will suffice for comparison to *Occiducrinus* gen. nov., proposed herein, and to be included in the Cyathocrinitidae. The shape of the cup of *Cyathocrinites* varies from a low, shallow, widely expanding bowl to an impressed, flat to rounded, upflaring-based, moderately high bowl to an upflaring, steep-walled cone. Forms with the bowl shape are by far the most common and show considerable latitude in slope of the walls from incurved to vertical to outflared. The five infrabasals (very rarely fused) may be nearly fully visible, only show the distal tips in lateral view, or be confined to the basal plane or basal invagination and not visible in lateral view. Ornamentation of the cup plates varies from smooth (rare) to finely granulate (most typical) to coarsely noded or spined (rare) to striate or ridged (rare). Sutures may be flush or more commonly weakly to moderately impressed. The stem, where known, may be pentagonal or circular in outline, sometimes grading from pentagonal to circular distally, and is normally heteromorphic. The tegmen (known on less than half the species assigned to the genus), is generally flat but may protrude gently to moderately and may or may not have a central opening. The anal sac, where known, is invariably a short to moderately high, stout tube projecting above the posterior interradius with an opening at or near the apex.

In summary, the generic concept of *Cyathocrinites* is based principally upon the presence of five infrabasals, narrow arm facets and a stout anal sac positioned laterally on the tegmen. At present species assigned to the genus show an extremely wide latitude of morphological features, undoubtedly representing intraspecific variation in part. A study of Silurian *Cyathocrinites* by Frest (1977) resulted in the recognition of three subgenera and three new species, knowledge of the palaeoecology of the genus, and a proposed phylogeny of the Silurian species of *Cyathocrinites*.

Webster and Lane (1987) pointed out the need for a systematic review of *Cyathocrinites*. Such a review would unquestionably enhance the stratigraphic, palaeogeographic, and phylogenetic value of the species assigned to the genus.

Genus OCCIDUCRINUS gen. nov.

Type species. *Occiducrinus australis* sp. nov. here designated.

Diagnosis. Cup elongate high cone, dicyclic, 3–4 IBB visible in side view, single anal in line of RR resting on pB, sutures slightly impressed, fine granular ornamentation on all cup plates; anal sac offset posterially; tegmen formed of double circlet of plates, inner circlet five large noded projecting OO; arms round, branching pattern unknown, numerous cover plates on ambulacral track.

Etymology. The generic name is derived from the Latin term *occidens*, meaning to the left or west, and refers to Western Australia where the specimens were found.

Description. See description of *Occiducrinus australis*.

Occiducrinus australis sp. nov.

Plate 2, figs. 1–3

Diagnosis. See diagnosis for the genus.

Types and locality. One partial crown, the holotype (UWA 27001) has tegmen, proximal brachials of three arms, and proximal three columnals preserved. Three partial cups, one designated a paratype (UWA 26996) has a part of the two subjacent basals and the A radial lacking but has well preserved radial facets and the stem facet; the other two (UWA 26999 and 27002) are so badly leached by solution and weathering that they are of no value other than they show radial facets. The specimens, except 27002, are from a calcareous sandstone in the upper part of the Wandagee Formation on the northeast side of a syncline along the North bank of the Minilya River, east of Coolkilya Pool, Western Australia. Specimen 27002, found by Dr Curt Teichert, was reported to occur 156 feet (48 m) above the red beds, from the southeastern part of S-Hill, West Kimberly, Western Australia. Precise horizon and locality not recorded.

Etymology. The trivial name, *australis*, is a Latin term meaning southern and the derivation of the term Australia. Thus the type species *Occiducrinus australis* could be loosely translated Western Australian crinoid.

Description. Cup elongate, high, gradually expanding with gently impressed sutures and fine granular ornamentation on all cup plates. IBB three or four, smaller in A radius if three, large ones in D and E radius when four; form high, nearly vertical-walled, rounded base with shallow invagination for stem attachment. BB five, hexagonal except heptagonal pB, slightly longer than wide, widest at distal ends of lateral sutures, gently

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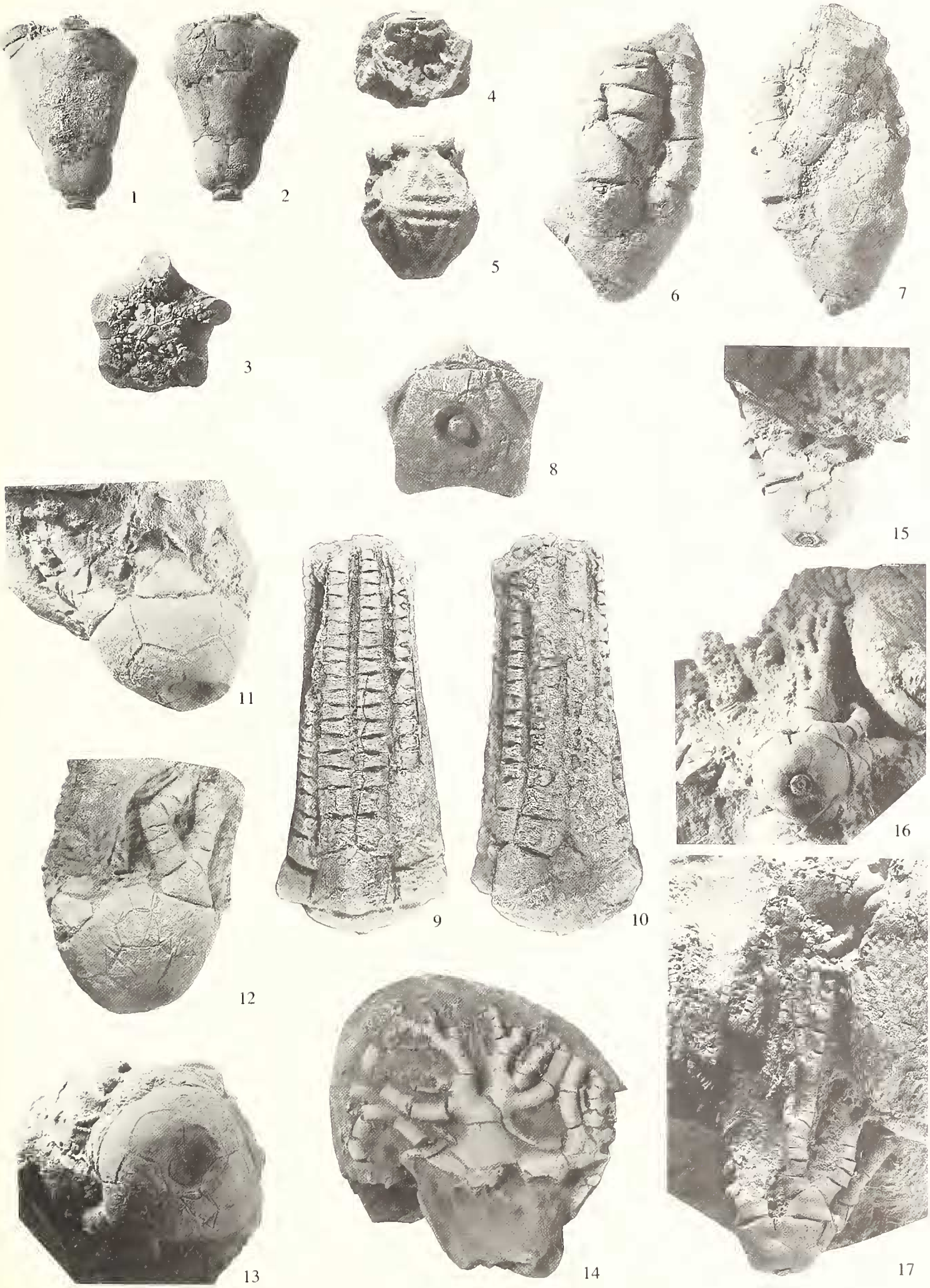
EXPLANATION OF PLATE 2

Figs. 1–3. *Occiducrinus australis* gen. and sp. nov.; A ray, CD interray, and oral views, respectively, of holotype UWA 27001; ×2.
Figs. 4, 5. *Eoindocrinus praecontignatus* Arendt 1981; oral and A ray views, respectively, of UWA 27003; ×2.
Figs. 6, 7. Rhenocrinidae gen. and sp. nov.; A ray and CD interray views, respectively, of UWA 83761; ×1.
Figs. 8–10. *Tapinocrinus spinosus* (Wanner 1924); basal, A ray, and CD interray views, respectively, of UWA 27000; ×2.
Figs. 11–13. *Anechocrinus nalbiaensis* gen. and sp. nov.; B ray, CD interray, and basal views, respectively, of holotype UWA 27008; ×1.
Fig. 14. Indeterminate inadunate crinoid; lateral view of partly preserved crown, UWA 83762; ×1·5.
Figs. 15–17. *Skaiocrinus granulosus* gen. and sp. nov.; CD interray, basal, and B ray views, respectively, of holotype UWA 21187; ×1.



WEBSTER, Permian crinoids

outflaring, moderately tumid transversely, gently tumid longitudinally. RR five, as wide as long, gently outflaring proximally, strongly incurved from base of facet, distal tips nearly horizontal, horseshow-shaped with oval to subcircular facet. Articular facet half as wide as radial, moderate to strong outward slope, shallowly excavated, interior smooth with weakly developed transverse ridge and central muscle area dividing facet into two ligament areas, an inner U-shaped area bordering the notch for the aboral coelomic canal and an outer half moon shaped area; transverse ridge divided into three parts, inner nodes and short ridges separated by irregular pits and short grooves, and two mirror image elongate lens-shaped ridges transverse to the central mass, no nerve canals present.

Anal plate large, rectangular, within radial circlet, adjoins pB and two adjacent radials, supports four small anal tube plates above, gently convex transversely and longitudinally, three-quarters as wide as high. Anal tube not preserved except for basal circlet of 11, possibly 12, small plates in posterior interradius between oral plates of tegmen adorally and C and D radials laterally and above anal plates externally. Tegmen formed of a double circlet of plates; outer circlet consists of 12 plates, three in each interradius, central one bridges interradial suture and adjoins oral plate of inner circlet, two lateral plates border on the central plate of the outer circlet and the radial supporting cover plates of ambulacral canal leading from brachials to the mouth beneath the inner circlet 00; elevated inner circlet of five 00, posterior largest adjoining anal sac and all four other 00, all other 00 bordered by one plate of outer circlet, two adjacent 00 and several cover plates of ambulacral canal, each 0 ornamented with a coarse node on outer ridge of flat distal surface, sutures between 00 slightly projecting along ridges. Only three arms have brachials preserved; primibrachs of A through C rays and secundibrach of B ray; all short, strongly convex outer surface nearly three times as wide as high; facets elliptical, deeper than wide; ambulacral tracks small, U-shaped.

Stem circular, heteromorphic, nodals with strongly rounded smooth latera or epifacets; internodal with smooth vertical latus; nodals four times as high as internodals; articular surface poorly preserved, on base of IBB circlet shows wide articulum of faint crenulae; lumen circular. Measurements are given in Table 2.

Remarks. Occiducrinus is distinguished by the high, elongate dorsal cup and three or four infrabasal plates, in contrast to the bowl-shaped or conical cup and five infrabasal plates in *Cyathocrinites*. The radial facets of *O. australis* resemble those of *Platycrinites hemisphericus* as described and illustrated by Van Sant (*in* Van Sant and Lane 1964, p. 56, fig. 17–4). However *P. hemisphericus* has short

TABLE 2. Measurements of *Occiducrinus australis*

	Holotype UWA 27001	Paratype UWA 26996
Cup		
Height (top orals)	29·2	32·7*
Width IBB circlet	11·1	14·0
Width BB circlet	18·8	22·4
Width RR circlet	22·4	24·8
Height IBB circlet	9·2	10.0
Height B (AB interray)	12·0	13·2*
Width B	10·0	11·6
Height pB	12·1	13·3
Width pB	10·3	9·6
Height R (B ray)	10·7	11·4
Width R	10·6	12·0*
Height anal X	8·1	7·9
Width anal X	5·9	7·0
Height IBr (A ray)	2·2	—
Width IBr	5·5	—
Height IIBr	2·8	—
Width IIBr	4·5	—
Diameter stem	5·2	—

* Estimated.

crenulae on the edge of the facet which are lacking in *O. australis* and *O. australis* has a central muscle area which is absent on *P. hemisphericus*. Preservation of the stereom on the holotype and paratype is excellent and even under higher magnification (× 64 to × 100) on standard stereoscopic binocular microscopes the fine mesh stereom for muscle attachment (Lane and Macurda 1975) can be seen to be confined to the transverse ridge with the coarse mesh stereom flooring the ligament areas.

Suborder POTERIOCRININA Jaekel, 1918
Superfamily RHENOCRINACEA Jaekel, 1918
Family RHENOCRINIDAE Jaekel, 1918

Rhenocrinidae gen. et sp. nov.

Plate 2, figs. 6 and 7

Material. One partial crown (UWA 83761) and a partial set of arms (UWA 27009), both from a yellow marl in the Wandagee Formation, south of Barrabiddy Dam, Wandagee Station, Western Australia; found by Dr Curt Teichert. Precise horizon and locality not recorded.

Remarks. A partial crown with a high broad turbinate-shaped cup, five? upflaring infrabasals, five upflaring basals, five highly upflaring radials, angustary radial facets with inset radial notches, three anals mostly in the cup, probably ten or more uniserial arms, strongly transversely convex cuneate brachials, large pinnules, and a slender prominent anal tube is assigned to the rhenocrinids as currently recognized in the Treatise (Moore and Teichert 1978, p. 673). Unfortunately the specimen lacks the stem and most of the A through C rays including some cup plates, making it unacceptable as a holotype.

Most rhenocrinids are of Devonian and early Carboniferous age and are known from Europe and North America. Only *Araeocrinus* is known from Upper Carboniferous strata of Texas. The rhenocrinids are not well defined and in need of study, as suggested by Webster and Lane (1987). thus a rhenocrinid from the Permian of Australia extends the stratigraphic and geographical range of the family, but the full significance of such a discovery must await the study of the superfamily and hopefully additional material from Western Australia.

Superfamily LOPHOCRINACEA Bather, 1899

Remarks. The discovery of specimens assigned to the Indocrinidae, Pachylocrinidae and Stellarocrinidae in the study material resulted in a comparison of the morphological features of the Lophocrinacea and related cladid inadunates.

The Lophocrinacea are defined in the Treatise by Moore *et al.* (*in* Moore and Teichert 1978) as having a conical cup with the infrabasals readily visible in lateral view, among other morphologically significant characters. Yet four of the six families assigned to the Lophocrinacea have all or most of the genera in each family with low to moderately high, bowl-shaped cups with the infrabasals downflaring (rarely), subhorizontal (commonly), or barely upflaring (rarely). Cup shape and character of the infrabasal circlet are two of the more important morphological features used in the classification of the cladid inadunates at the superfamily, family and generic levels (Moore and Teichert 1978). Thus it is surprising to find a superfamily defined on a set of morphological characters and more than half the genera assigned to it not conform. With the exception of the Pelecocrinidae, each family of the Lophocrinacea is considered by me to have unifying morphological characters that allow the proposal of phylogenetic lineages within the family. Above the family level, the Lophocrinacea are a heterogeneous group which requires reclassification. The following changes are recommended.

Morphological affinities of the Texacrinidae and Pachylocrinidae were recognized by Moore and Strimple (*in* Moore and Teichert 1978) when they considered the pachylocrinids to be the progenitor of the texacrinids. The pachylocrinids have peneplenary arm facets whereas the texacrinids have plenary arm facets and arm branching patterns are modified in the texacrinids. The Pachylocrinidae are judged to be more closely allied to the texacrinids than the lophocrinids and therefore placed in the Texacrinacea.

Moore *et al.* (*in* Moore and Teichert 1978) suggested that the Stellarocrinidae were derived from the Pachylocrinidae. The cup structure of the two families is more closely related than that of the stellarocrinids and the lophocrinids. The arm structure of the stellarocrinids is different from both the pachylocrinids and lophocrinids, but could easily be modified from the pachylocrinids by outflaring and development of biserial brachials. The stellarocrinids are also transferred to the Texacrinacea.

The Laudonocrinidae are assigned to the Pirasocrinacea. Similarities of the Laudonocrinidae and the Pirasocrinidae were discussed and the validity of the former justified by Moore and Strimple (*in* Moore and Teichert 1978). The Laudonocrinidae are considered the progenitor of the Pirasocrinidae.

Four genera previously assigned to the pelecocrinids are transferred to other families. *Forthocrinus* has a low, bowl-shaped cup and interplate ornamentation similar to *Stellarocrinus* and other stellarocrinids, and is therefore assigned to the Stellarocrinidae. *Tetrabrachiocrinus* is assigned to the Laudonocrinidae because it has a low, widely expanding cup, among other features, similar to *Bathronocrinus* and *Paianocrinus*. *Malaiocrinus* and *Depaocrinus* are transferred questionably to the Pachylocrinidae because of similarity of cup features with a lack of knowledge of the arms. This leaves only two genera, *Pelecocrinus* and *Exoriocrinus*, in the Pelecocrinidae, which along with the Lophocrinidae, are accepted in the Lophocrinacea.

The Indocrinidae were removed from the Lophocrinacea and placed in the superfamily Cromyocrinacea by Arendt (1981) as he considered that they were derived from *Ureocrinus*. I tentatively concur with Arendt's assignment.

Superfamily CROMYOCRINACEA Bather, 1890
Family INDOCRINIDAE Wanner, 1916
Genus EOINDOCRINUS Arendt, 1981

Eoindocrinus praecontignatus Arendt, 1981

Plate, figs. 4 and 5

Material and locality. One cup, UWA 27003, from a fine grained sandstone in the upper part of the Wandagee Formation, northeastern side of a syncline, north bank of the Minilya River east of Coolkilya Pool, Western Australia. Precise horizon and locality not recorded.

Remarks. The cup referred to *Eoindocrinus praecontignatus* is crushed inward on the CD interray destroying partly the BC through DE basals. Three small anal plates below the radial summit are weathered and recognizable but rather difficult to define. Grooves and ridges which extend across plate boundaries form a radiating triangular ornamentation pattern. Primary ridges converge in the centre of the basals. Secondary ridges form triangles between the primary ridges. The triangles are not always well developed as some legs tend to curve inward and end before reaching another leg of the triangle.

The ornamentation pattern is very similar to that of specimens of *E. praecontignatus* Arendt, 1981 (pl. 18) from the upper Artinskian of the Ural Mountains. This is the first report of *Eoindocrinus* from an area outside Russia. *E. praecontignatus* supports a late Artinskian age for the Wandagee Formation. Indocrinids are moderately common in the Timor faunas. Thus an indocrinid in the Western Australian faunas shows additional affinities with the Timor faunas.

Superfamily ERISOCRINACEA Wachsmuth and Springer, 1886
Family GRAPHIOCRINIDAE Wachsmuth and Springer, 1886
Genus TAPINOCRINUS Webster, 1987

Tapinocrinus spinosus (Wanner, 1924)

Plate 2, figs. 8–10

Material and locality. One crown, UWA 27000, from a fine-grained sandstone in the upper part of the Wandagee Formation along the Lyndon River, Western Australia. This is the same general locality and stratigraphical interval given for *Stomiocrinus ferruginus*. It is unknown if these species were associated or from different horizons.

Remarks. One crown of *T. spinosus* shows the distal arm structure of the species which was based on an incomplete partial crown (Wanner 1924). There are ten arms with the primibrachs axillary in all rays. The A and D primibrachs are higher than the other three primibrachs. All secundibrachs are slightly cuneate with a pronounced, blunt to moderately sharp, short spine or node in the centre of the plate. The blunt spined primibrachs form a good pentagonal outline in basal or oral view.

T. spinosus is an advanced member of the genus with a low, discoid cup lacking ornamentation. This is the first report of *T. spinosus* outside Timor. Webster (1987) reported two species, *T. macurdai* and *T. ingrami*, from the Callytharra Formation at Callytharra Springs, Western Australia. These species have higher cups that are ornamented. Species of *Tapinocrinus* are potential zone fossils for the Permian strata of Western Australia.

Measurements. Crown height 31·9, width 14·7; cup height 3·0, width 11·3; H/W ratio 0·27; B height 2·1, width 2·9; R height 3·1, width 6·0; IBr (A ray) height 5·6, width 6·6; B ray IBr height 4·0, width 6·5; $IIBr_1$ A ray height 2·9, width 3·3; $IIBr_2$ height 2·4, width 3·2; $IIBr_5$ height 1·3, width 3·1; $IIBr_{10}$ height 1·0, width 2·2; diameter stem impression 2·0.

Superfamily TEXACRINACEA Strimple, 1961

Emended Diagnosis. Crown tall and slender, cup bowl-shaped with basal concavity and steep sides near rim, arm facets peneplenary to plenary, one to three anals in cup, anal sac tall, composed of longitudinal rows of plates, arms uniserial or biserial, long, commonly many (up to 40) but five or ten in some. Carboniferous–Permian.

Remarks. The Pachylocrinidae and Stellarocrinidae are transferred to the Texacrinacea as explained in the remarks under the superfamily Lophocrinacea.

Family PACHYLOCRINIDAE Kirk, 1942
Genus SKAIOCRINUS gen. nov.

Type species. *Skaiocrinus granulosus* sp. nov., here designated.

Diagnosis. Crown elongate, expanding distally; cup low, truncate bowl-shaped, base slightly concave, small impressions at apices of basals and radials; infrabasals gently downflared, not visible from side, mostly covered by proximal columnal; radial facets wide, peneplenary, bearing transverse ridge and ligament pits; arms branching isotomously on axillary first primibrach, branch exotomously at least three times; brachials strongly convex transversely, slightly cuneate; one pinnule per brachial on alternate sides of arm; three anals in cup; granular ornamentation on cup plates and proximal brachials; proximal stem transversely round, lumen pentalobate.

Etymology. The generic name, *Skaiocrinus*, is derived from the Greek word *skaios*, meaning left and western. It is used in reference to Western Australia.

Description. See description of *S. granulosus* gen. et sp. nov.

Remarks. When Moore and Plummer (1940) named *Texacrinus* they recognized that it was similar to *Pachylocrinus*, but differed by having plenary radial facets and an exotomous arm branching pattern. *Skaiocrinus* is transitional between the two genera, that is, the arms branch exotomously like *Texacrinus* and the radial facets are peneplenary as in *Pachylocrinus*. Arguments could be made to include *Skaiocrinus* in the Texacrinidae because of the exotomous arm branching pattern. Because the type of radial facet, angustary to plenary, is used at the superfamily level in the classification of the Inadunata, *Skaiocrinus* is placed in the Pachylocrinidae.

Skaiocrinus granulosus sp. nov.

Plate 2, figs. 15–17

Diagnosis. Characters of the genus.

Type and locality. One crown and two fragmentary arms of a second specimen associated with a large specimen of the productid brachiopod *Taeniothaerus* in a single block of calcareous siltstone, UWA 21187, found by Dr Curt Teichert in the east limb of a syncline north of the Minilya River, west of Coolkilya Pool, Western Australia. Precise horizon not recorded.

Etymology. The trivial name refers to the granular surface ornament on the cup and proximal brachial plates.

Description. Crown medium size, slender at base expanding upward with additional arm branchings. Cup medium high, truncate, bowl-shaped, walls slope gently outward, basal invagination slight; granulose ornamentation, small pits at apices of BB and RR. IBB five, small, confined to basal invagination, subhorizontal to slightly downflaring, proximal parts covered by proximal columnal, not visible in lateral view. BB five, pentagonal (BC basal hexagonal) moderately convex transversely, strongly convex longitudinally, downflaring proximally and upward outflaring distally. RR five, wider than high, moderately convex transversely and straight to gently convex longitudinally, radial facet peneplenary, small radial gape; facets slope gently out and downward; B radial facet partly exposed by broken IBr showing large denticulate outer marginal ridge, very narrow ligament furrow and outer ligament ridge externally to fairly large ligament pit; denticulate outer marginal ridge visible in lateral view of all rays, no other details observable. Anals, three in cup, pA largest bordered by C radial, BC basal, CB basal, D radial and two overlying anal plates; anal X second largest, distal portion above cup summit; right tube plate or tertanal small, less than half below summit of cup, barely adjoins pA. Brr strongly convex transversely, slightly concave longitudinally on IBr and $IIBr_{1-3}$ and straight on all more distall Brr, usually wider than high, arm branching isotomous on axillary IBr in all rays, exotomous thereafter on $IIBr_{5or7}$, $IIIBr_6$, $IVBr_5$, and VBr_6 in visible E ray, possibly one higher branching, thus 50 or 60 arms probable. Poorly preserved column transversely round, with well-developed crenularium and areola; lumen pentalobate, probably heteromorphic.

Measurements. Crown height 59·5; cup height 7·6, width maximum 14·8, width minimum 13·6, width average 14·2; diameter IBB circlet 4·2; BB height 4·8, width 5·0; RR height 5·3, width 7·5; $AIBr_1$ height 4·6, width 6·8; $IIBr_1$ height 3·5, width 4·6; $IIBr_2$ height 2·7, width 3·2; $IIBr_3$ height 1·9, width 3·0; $AIIBr_5$ height 2·8, width 3·0; diameter columnal 3·2.

Family STELLAROCRINIDAE Strimple, 1961
Genus ANECHOCRINUS gen. nov.

Type species. Anechocrinus nalbiaensis sp. nov. here designated.

Diagnosis. Stellarocrinid with medium high, unornamented, bowl-shaped cup; five IBB confined to weak basal invagination; sutures flush; three anals in cup; radial facets peneplenary, outflaring radial notches visible in dorsal or ventral view; arms uniserial branching isotomously on first primibrach and fourth secundibrach; stem facet roundly pentalobate, lumen pentalobate.

Etymology. The name is from the Greek *anecho*, meaning hold back or retain, in reference to the primitive nature of three anals retained within the cup.

Remarks. The outflaring, widely branching arms of *Anechocrinus* are typically developed in the stellarocrinids. Only two other genera of the stellarocrinids have three anals in the cup, these are *Heliosocrinus* Strimple, 1951 (Upper Mississippian, North America) and *Pedinocrinus* Wright, 1951 (Lower Carboniferous, Scotland), both of which have low cups with slightly cuneate brachials and weakly peneplenary arm facets. *Heliosocrinus* has coarse interplate ridge ornamentation on the cup whereas *Pedinocrinus* is smooth. *Anechocrinus* has a higher cup than either *Heliosocrinus* or *Pedinocrinus* and more obvious radial notches.

The cup of *Anechocrinus* resembles the four-rayed cup of *Depaocrinus* Wanner, 1937, agreeing in the shape, basal invagination, smooth surface and presence of three anals in the cup; unfortunately the arms of *Depaocrinus* are unknown. Wanner (1937, p. 153) pointed out that it is not known if the four-rayed condition of the only known specimen of *Depaocrinus* is an abnormality or of generic character as several other genera in the Permian of Timor are four-rayed. Until the arm structure of *Depaocrinus* is known its family assignment remains uncertain.

Stellarocrinids are most abundant in the late Carboniferous of North America. *Anechocrinus* is interpreted to be a conservative member of the family which apparently adapted to a sand substrate in the Permian of Western Australia.

Anechocrinus nalbiaensis sp. nov.

Plate 2, figs. 11–13

Diagnosis. Characters of the genus.

Types and locality. One slightly distorted crown (the holotype, UWA 27008), crushed along the E-ray, protruded along C-ray, and one partial cup with proximal brachials UWA 27030. The holotype, found by Dr Curt Teichert, is from the *Lingula* horizon in the Quinannie Shale, Carnarvon Road, Nalbia Paddock, south of Wandagee Station, Western Australia. No locality information is available for the partial cup. Both specimens are from fine-grained sandstones of similar lithology, suggesting a common locality and horizon.

Etymology: The trivial name refers to Nalbia Paddock where the holotype was found.

Description. Crown low, widely splayed, isotomously branching arms. Cup medium high, bowl-shaped, unornamented, weak basal invagination, walls gently outflaring becoming vertical to slightly inturned at summit; five IBB small, downflaring, confined to basal invagination, mostly covered by stem impression; five BB pentagonal except hexagonal pB, downflaring proximally, strongly recurved, moderately outflaring distally, gently convex laterally, slightly wider than high; RR half again as wide as high, gently convex longitudinally and transversely, facets peneplenary sloping outward, facet surface not exposed, radial notches obvious in lateral view, weakly concave in basal view; three anals in cup, primanal pentagonal adjoining C radial, posterior basal, D radial and two overlying pentagonal anal plates both of which project half above cup summit; primaxils strongly convex transversely, gently convex longitudinally, form gape with radials along suture, IIBrr and all subsequent Brr strongly convex transversely, straight to weakly convex longitudinally, weakly cuneate; $IIBr_4$ axillary; all branchings isotomous, widely splayed, probably at least one additional branching after that on $IIBr_4$; stem impression roundly pentagonal, crenularium of 35 rounded crenulae, areola pentagonal, lumen pentalobate; anal sac unknown.

Measurements. Crown height 37·0 incomplete; cup height 11·9, maximum width 15·8, minimum width 13·8, average width 14·8; width IBB circlet 8·0; BB height 8·0, width 9·6; pB height 7·8, width 9·8; RR height 8·4, width 13·9; IBr height 6·5, width 10·0; $IIBr_1$ height 4·2, width 5·8; $IIBr_2$ height 2·6, width 4·5; $IIBr_3$ height 2·3, width 4·0; $AIIBr_4$ height 2·8, width 4·0; anal x height 6·2, width 6·3; stem impression diameter 4·7

Superfamily CALCEOLISPONGIACEA Teichert, 1954
Family CALCEOLISPONGIIDAE Teichert, 1954
Genus CALCEOLISPONGIA Etheridge, 1915

Calceolispongia abundans Teichert, 1949

Plate 3, figs. 6–9

Material and locality. Five cups and crowns (UWA 83756–83760) from a boulder of fine-grained sandstone of the Wandagee Formation in the bed of Minilya River between Coolkilya Pool and Curdmuda Well, Western Australia. Teichert (1949) reported *C. abundans* as particularly common in a sandstone bed between 120 and 135 feet (37–41·5 m) above the *Calceolispongia* Stage of the Wandagee Formation in the syncline west of Coolkilya Pool. The boulder of this study was probably eroded from that interval and transported downstream to the locality where it was found, which was not precisely recorded.

Remarks. A block of fine-grained sandstone of the Wandagee Formation yielded five specimens of *C. abundans*, one with the proximal parts of the arms and stem still articulated. In addition the remainder of other arms are closely associated possibly from this same specimen. Two other specimens from the same block have the proximal part of the stem attached.

No morphological detail can be added to Teichert's description (1949, p.54) of the cup and arms of *C. abundans*, however, some information can be added to the interesting proximal stem. One crown has 34 mm and one cup has 106 mm of proximal stem preserved. These consist of a heteromorphic series of nodals and priminternodals (pluricolumnal pattern Type II, Webster 1974). In a pluricolumnal series 60 mm from the cup measurements of heights of plates are: nodal 1·1 mm; priminternodal 0·7 mm; and secundinternodal 0·5 mm. All columnals have rounded epifacets and symplectial articulation. Articulum divided into crenularium and areola. Crenularium narrow (width one-eighth of stem diameter) with straight coarse rounded crenulae. Areola wide (diameter 3 mm with stem diameter of 4 mm), shallow depression. Lumen pentagonal. Proximal columnals weakly pentagonal in outline, distal columnals circular in outline. Attached cirri are homeomorphic with straight smooth latera. Proximal cirri short, 5 mm to 14 mm, composed of very short cirrals, distally tapering to pointed ends; distal cirri long, at least 45 mm (incomplete), composed of long cirrals, believed to also taper on distal tips. Articulum of cirri same as that of columnals.

Teichert (1949, p. 58) listed the subpentagonal outline of the column of *C. abundans* as one of the possibly important distinguishing features of the species. From the description of the stem given above it is obvious that this is true only for proximal parts of the stem. More complete stems of the different species of *Calceolispongia* are needed to understand their relationships fully.

Teichert (1949, p. 30) speculated that the stem of *Calceolispongia* was entirely functionless. The size of *C. abundans* and extended development of the basals suggest that it rested the expanded central part of the basals on the substrate. Study of modern stemmed crinoids by Macurda and Meyer (1974) has shown that for some forms the distal cirri are used to burrow into soft substrate and anchor the animal while other medial cirri on the same individual may act only as props. The extended stem and lengthy cirri on *C. abundans* undoubtedly served as an anchoring device in the

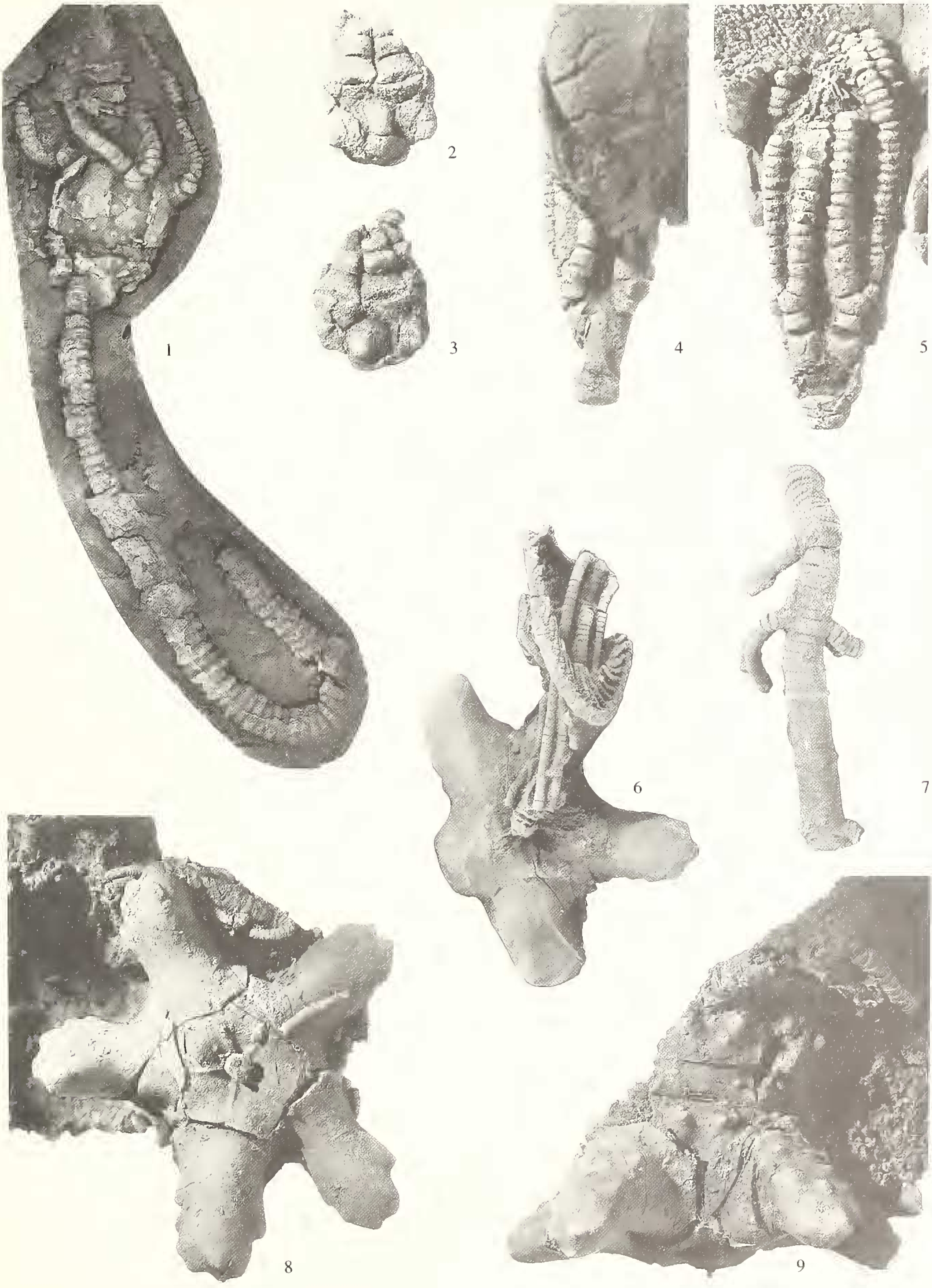
EXPLANATION OF PLATE 3

Fig. 1. *Dichocrinus*? *gerringgongensis* sp. nov., CD interray view, holotype UWA 62961; ×1.

Figs. 2, 3. *Jimbacrinus minilyaensis* sp. nov., B–C rays and D–E rays views, respectively, holotype UWA 83763; ×2.

Figs. 4, 5. *Stomiocrinus ferruginus* sp. nov., CD interray and B–C rays views, respectively, holotype, UWA 27006; ×2.

Figs. 6–9. *Calceolispongia abundans* Teichert 1949. 6, basal view of crown showing attached proximal column and an associated arm fragment; UWA 83756, ×0·75. 7, lateral view of pluricolumnal segment originally attached to specimen of fig. 6, UWA 83756, ×1·5. 8, 9, basal and A ray views, respectively, of UWA 83757, ×1.



WEBSTER, Permian crinoids

fine-grained sand substrate where they lived. Using the proximal cirri as props they may have elevated themselves a few centimetres above the sediments. This would have allowed them to obtain a more favourable feeding position and to move upward keeping pace with sedimentation. This supports the feeding posture as interpreted by Willink (1979*b*) for species of *Calceolispongia* studied in eastern Australia.

Species of *Calceolispongia* are common in Western Australia, eastern Australia, and Timor. They are of stratigraphic use in eastern Australia and Western Australia (Willink 1979*b*; Teichert 1949) and were perhaps the most successful evolutionary lineage in the colder water and sand substrate environments of Australia. They clearly indicate migration pathways were open between eastern and Western Australia in the early Permian. They also raise further questions on the late Permian age of the Basleo faunas.

Genus JIMBACRINUS Teichert, 1954

Jimbacrinus minilyaensis sp. nov.

Plate 3, figs. 2 and 3

Diagnosis. A *Jimbacrinus* with granular ornamentation on all cup plates and first primibrachs, basals bulbus to bluntly spinose, no coarse nodes on radials.

Types and locality. Two partial crowns, the holotype UWA 83763 and the paratype UWA 83764 from a sandstone in the Wandagee Formation, northeast side of syncline north of Minilya River, east of Coolkilya Pool, Western Australia. Precise horizon not recorded.

Etymology. The trivial name is derived from the Minilya River, along which both specimens were found.

Description. Crown slender, elongate; dorsal cup bowl-shaped, base gently convex; five IBB very weakly upflared, proximal quarter covered by stem impression; five BB hexagonal, except heptagonal posterior B, slightly higher than wide, moderately to strongly convex with pronounced central enlargement or blunt node. Five RR pentagonal, half again as wide as high, subvertical, gently convex transversely; cup sutures flush except pit at apices of RR and BB; radial facets plenary, surfaces not exposed; primanal nearly equidimensional, distal end may project slightly above radial summit, adjoined by two tube plates, both C and D radials and posterior B; fine granular ornamentation on all cup plates.

Arms, five, atomous; IBr_1 nearly twice as wide as high, narrowing distally; IBr_2 rectangular, half again as wide as high; may possess two blunt coarse nodes laterally to one another; all higher Brr strongly cuneate, convex transversely, with pinnule facet on wide side, very rounded in oral view with wide V-shaped ambulacral tract.

Anal sac composed of thin plates extending at least to IBr_4 in height. Stem impression round, column not preserved. Measurements are given in Table 3.

Remarks. *Jimbacrinus minilyaensis* is a much smaller form and lacks the coarse nodes or spines on the radials of *J. bostocki* Teichert, 1954. Both the holotype and paratype are slightly crushed. The paratype is smaller than the holotype and is considered to be an immature form. Immaturity of the paratype is reflected in the near absence of the nodes on the second brachial and lesser development of the central enlargement or blunt node on the basals. The granular ornamentation is poorly preserved on the basals and infrabasals.

Family and genus indeterminate

Plate 2, fig. 14

Material and locality. One partial crown, UWA 83762, from a red claystone in the Wandagee Formation, south of Barrabiddy Dam, Wandagee Station, Western Australia; found by Dr Curt Teichert.

TABLE 3. Measurements of *Jimbacrinus minilyaensis*

	Holotype UWA 83763	Paratype UWA 83764
Cup height*	5·7	3·7
Diametre IBB circlet	4·8	—
Height B	3·8	3·3
Width B	3·2	3·3
Height R	2·6	1·8
Width R	4·2	3·6
Height pA	1·8	1·4
Width pA	2·4	1·3
Height IBr_1	2·2	1·7
Width IBr_1	3·8	3·4
Height IBr_2	1·4	1·0
Width IBr_2	2·7	2·0
Diameter stem impression	1·8	—

* Crushed specimens.

Description. Crown low, as wide as long. Cup medium cone, base impressed, approximately half (16 mm) height of estimated crown height (31 mm). Radials with elevated angustary facets. Arms ten or more per ray, inner eight weakly zigzag, outer two gently convex laterally; all brachials strongly convex transversely, gently convex to straight longitudinally. IBr_1 wider (4·5 mm) than long (2·8 mm), axillary; $IIBr_1$ wider (3·4 mm) than long (2.2 mm), axillary. Outer IIIBr slightly more than twice as long (4·0 mm) as wide (1·9 mm), strongly rounded exterior; succeeding 3 brachials of same shape, but becoming shorter distally, Inner $IIIBr_1$ wider (3·2 mm) than long (2·2 mm), axillary; succeeding brachial slightly cuneate, longer (2·2 mm) than wide (1·8 mm), bearing slender elongate pinnule on outer side. At least two additional branchings on $IIIBr_3$ and $IVBr_4$. Stem unknown.

Remarks. This specimen is crushed and has been partly destroyed by erosion. However, the cup shape and dicyclic condition are recognizable from the outline and trace of the plates along the edges where eroded. The arms are distinctive. The unbranched outer two arms of each ray are enlarged pinnules which form a horseshoe-shaped structure with the zigzag arms inside. Several cladid inadunates have weakly zigzag arms, such as species of *Ramulocrinus* and *Gilmocrinus*. However, these Lower to Middle Carboniferous forms have only ten arms, the crowns are elongate, and the cups lack basal invaginations. The basal invagination and branching of the arms on the single primibrachials and secundibrachials in each ray are advanced conditions. Unfortunately the specimen cannot be assigned to any known cladid family without question.

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